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WELDING SECTION

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ABSTRACT

Submerged-arc welds were prepared in a pipeline fittings steel, A633 Grade E, using a series of commercially available wire/flux consumable combinations. The weldments were quenched and tempered in order to achieve the targeted mechanical properties of 552 MPa yield strength and a notch toughness of 40J at -40°C.

Although the required tensile properties were obtained in all of the quenched and tempered weld metals, the required notch toughness was achieved only with one wire/flux consumable combination.

Improved weld metal notch toughness should be possible with the quench and temper heat treatment provided an acicular ferrite microstructure with a limited precipitation of carbo-nitride particles is developed. A weld metal composition of low carbon (<0.1%) combined with reduced levels of Mo ($\leq$0.25%), Ni ($\leq$0.50%) and V+Nb ($\leq$0.020%) is recommended.

LABORATOIRES DE RECHERCHE EN MÉTALLURGIE PHYSIQUE
RAPPORT PMRL 85-59 (TR)

PROPRIÉTÉS MÉCANIQUES DES MÉTAUX DE SOUDURE À L'ARC SOUS FLUX DANS LES RACCORDS DE CANALISATIONS TREMPÉS ET REVENUS

par

J.T. McGrath, M.W. Letts et J.A. Gianetto

RÉSUMÉ

On a effectué des soudures à l'arc sous flux dans des raccords de canalisations en acier A633 de qualité E en utilisant une série de combinaisons fil-flux commerciales. Les pièces soudées ont été trempées et revenues dans le but d'atteindre les propriétés mécaniques fixées soit une résistance élastique de 552 MPa et une résistance à l'entaille de 40 J à -40°C.

Bien que la résistance à la traction requise ait été obtenue pour tous les métaux de soudure trempés et revenus, la résistance à l'entaille désirée n'a été atteinte qu'avec une seule combinaison fil-flux.

Il sera possible d'améliorer la résistance à l'entaille du métal de soudure par un traitement thermique de trempe et de revenu, à condition de mettre au point une microstructure de ferrite aciculaire avec une précipitation limitée de particules carbonitrurées. On recommande donc d'utiliser un métal à faible teneur en carbone (<0,1 %) combiné à de faibles teneurs en Mo ($\leq$0,25 %), Ni ($\leq$0,50 %) et en V+Nb ($\leq$0,020 %).

INTRODUCTION

Recent research[1] on methods for achieving the required mechanical properties of welds in high-strength pipeline fittings indicated that the strength and notch toughness properties were difficult to obtain using a normalizing and stress relieving heat treatment. For example, if precipitation hardening was produced (formation of V and Mo carbides), the yield strength of the submerged-arc weld increased but the notch toughness of the weld decreased.

It was felt that high strength, tough weld metals may be achieved by quenching and tempering of low carbon, lean alloy weld compositions. The quench and temper treatment should result in a fine-grained structure with a minimum of alloy carbide precipitation.

Therefore, the objective of the program was to study the effect of quenching and tempering on producing high strength (yield strength 552 MPa), tough (40J at -40°C) submerged-arc-weld metals for pipeline fittings.

EXPERIMENTAL

Materials

An ASTM A633 Grade E steel, 23 mm thick was selected as the base metal. The composition of the steel, listed in Table 1, was in compliance with the pipeline fittings code, Canadian Standards Association Z245.10-M1979. Welding consumables were selected to provide relatively lean weld deposit chemistries which would have sufficient hardenability to meet the required strength and notch toughness properties in the quenched and tempered condition. As shown in Table 1, the welding wires contained Ni, Mn, and Mo as the principal alloying elements. High basicity fluxes were chosen, Table 2, to reduce the weld metal inclusion content.

Welding Procedure

The experimental welds were deposited using the submerged-arc-welding process. The welds were prepared using a single wire (4.0mm diam.) multi-pass welding technique. The plates were prepared with a 60 degree included angle bevel and a 3 mm land to form a single-vee joint preparation. Each weldment was preheated to 120°C and tack welded using E48018 shielded-metal arc electrodes. Details of the joint design and pass sequence are shown in Fig. 1(a). While maintaining the preheat, the first side of the joint was completed using a heat input of 2 kJ/mm. A maximum interpass temperature of 200°C was maintained throughout all welding. The plate was turned over, backgouged by carbon-arc and filled with approximately four passes. A typical macrosection is shown in Fig. 1(b). Welding parameters used for the experimental welds are listed in Table 3.

All welds were subjected to a nondestructive examination to ensure that they were free from defects. After acceptance, each weld was given a post-weld heat treatment which consisted of heating to 925°C for 1 h, water quenching and tempering for 1 h at 650°C.

Mechanical Testing and Microstructure Analysis

The tensile properties, and hardness were determined for the base metal and weld metals in the quenched and tempered condition. All weld tensile specimens were machined with their longitudinal axis parallel to the welding direction.

Full Charpy impact transition curves were obtained. The specimens were taken from the half-thickness position with the notch in the through-thickness direction.

Optical microscopy was used to identify and characterize the microstructural constituents of the quenched and tempered weld metals.

RESULTS

Mechanical Properties

The tensile properties of the base metal and weld metals in the quenched and tempered condition are listed in Table 4. For both base metal and weld metals, the tensile strength exceeded the target of 552 MPa yield strength and 635 MPa ultimate strength. Adequate ductility was achieved. In the case of the weld metals, the increase in strength corresponded with the increase in hardenability (Table 6). A similar trend was found for weld metal hardness as shown in Table 5.

The notch toughness properties of the base metal and weld metals are shown by the Charpy transition curves in Fig. 2. Only weld PF1 met the Charpy energy requirement of 40 J at -40°C. Welds PF2 and PF3 exhibited less than 15 J of impact energy at -40°C.

Weld Composition and Microstructure

The composition of the welds are listed in Table 6. The composition was dependent upon the composition of the wire, the contribution from slag/metal reactions, and dilution from the base metal (about 20%).

The weld metal microstructures are shown in Figs. 3 to 5. Weld PF1 contained a predominantly fine grained, acicular ferrite structure with some bainite and martensite regions. The acicular ferrite microstructure was primarily responsible for the acceptable low temperature notch toughness properties. Welds PF2 and PF3 (Fig. 4 and 5) contained a high proportion of lath martensite and bainite which resulted in the drop in low temperature toughness as shown in Fig. 2.

One might expect the very fine ferrite structure of the base metal (Fig. 6), produced by quenching and tempering, to

result in the highest notch toughness. However, as shown in Fig. 2, the toughness of the base metal was significantly lower than PF1 weld metal. The higher carbon level of the base metal resulted in the precipitation of a high volume fraction of carbide particles upon tempering. Carbides are known[2,3] to reduce notch toughness.

DISCUSSION

The results of the program have shown that high strength (target 552 MPa yield strength) can be obtained in pipeline fittings weld metals using a quench and temper post-weld heat treatment. However, the required notch toughness properties were only obtained with one wire/flux consumable combination.

In order to meet the required goals of strength (552 MPa yield strength) and notch toughness (40 J at -40°C) in quenched and tempered weld metals the weld chemistry and microstructure must be optimized.

The recent work of Croft et al.[4] on the effect of post-weld heat treatment on the toughness of submerged-arc-weld metals in microalloy linepipe steel can provide some insight into the chemistry/microstructre optimization in quenched and tempered weld metals. Croft et al. found that a quenched and tempered weld microstructure that consisted of a high proportion of acicular ferrite or low carbon martensite resulted in a notch toughness level of 50 J at -50°C. They also indicated that precipitation of Nb or V carbo-nitrides should be minimized. Furthermore, the formation of ferrite with aligned second phase or high-carbon lath martensite, both detrimental to toughness, should be avoided.

In order to produce an acicular ferrite or low-carbon martensite structure in the quenched and tempered weld metal, it is essential to ensure the level of carbon is less than 0.1%. In addition, the amounts of alloying elements, i.e., Mo, Ni and Mn which contribute to increased hardenability should also be limited to the suggested levels listed in Table 7. The levels of Mo, Ni and Mn are estimates only and require experimental verification.

In order to avoid excessive precipitation of carbo-nitrides during tempering the Nb+V content should be controlled to _0.020% as indicated in Table 7. This level of Nb+V was based on the findings of Croft et al.(4).

The composition of the welds produced in the present study can be compared with the proposed optimum weld-metal chemistry listed in Table 7. In weld PF3 the levels of C, Ni, Mo, Nb and V exceeded the proposed levels. This has resulted in a microstructure of lath martensite and bainite (Fig. 5). Although the volume fraction of Nb, V carbo-nitrides, produced by tempering, was not measured, it was assumed that sufficient precipitates had formed to lower the notch toughness. Weld PF2 had an excessive amount of C and Mo, the most important elements contributing to hardenability. The presence of both martensite and bainite in weld PF2 was a reflection of the excessive hardenability and resulted in decreased toughness. As in the case of weld PF3, the presence of Nb and V provided the potential for carbo-nitride precipitation during tempering.

The improved notch toughness of weld PF1 can be attributed to lower hardenability because of the reduced level of Mo, resulting in an acicular ferrite microstructure. It was anticipated that a further improvement in toughness could be obtained with reductions in C, Nb and V levels in this weld.

The reduction of C in the weld metals can be achieved by lowering the C in the base metal to approximately 0.06%. If the submerged-arc-welding wire is used with a level of 0.1% C, dilution from the base metal should result in a weld-metal carbon content of the order of 0.06 to 0.08%.

The control of the other key elements, i.e., Mn, Ni, Mo, Nb and V in the weld metal will depend upon the composition of the wire and the amount of dilution from the base metal.

The lean microalloy steels presently available should be able to meet the required fittings strength (552 MPa) and toughness (40 J at -40°C) property values after quenching and tempering. For example, the work of Boyd(5) has indicated that acceptable mechanical properties (yield strength 592 MPa, 68 J impact energy at -29°C) were obtained in a lean, control-rolled

microalloy steel (C=0.06, Mn=1.43, Ni=0.075, Mo=0.010, Nb=0.07) by quenching and tempering after rolling.

In summary, submerged-arc-weld metals with the composition proposed in Table 7, should contain an acicular ferrite microstructure and an acceptable volume fraction of carbo-nitride precipitates after quenching and tempering. This weld-metal microstructure should provide the required strength (552 MPa) and notch toughness (40 J at -40°C) properties for pipeline fittings application.

ACKNOWLEDGEMENTS

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REFERENCES

1. J.T. McGrath, M.W. Letts, J.A. Gianetto, D.W. Rigby and M.R. Tomkins, J. Mat. for Energy Systems, 6, 1, p. 24, 1984.
2. R.E. Dolby, Met. Construction, 13, p. 704, 1981.
3. P.R. Kirkwood, Proc. Int. Symp., "Niobium '81", AIME, San Francisco, 1981.
4. N.H. Croft, J.M. Gray and A.J. DeArdo, Pro. Int. Conf. High Strength Low Alloy Steels, Philadelphia, Oct., 1983.
5. J.D. Boyd, Met. Trans., 7A, p. 1577, 1976.

Table 1. Chemical composition of base material and welding wires

Material	Element, wt. %												
	C	Mn	Si	S	P	Al	Ni	Cr	Mo	Cu	V	Nb	Sn
A633 Gr E	0.20	1.45	0.32	0.007	0.023	0.02	0.17	0.07	0.13	0.19	0.080	0.035	0.005
SD3 - 1 Ni	0.09	1.58	0.15	0.018	0.012	-	1.23	0.04	<0.01	0.13	<0.005	<0.005	0.025
Autorod 12:34	0.10	1.52	0.24	0.014	0.009	-	0.05	0.05	0.53	0.36	<0.005	<0.005	0.025
SD3 1 Ni 0.5 Mo	0.09	1.51	0.23	0.013	0.007	-	1.00	0.05	0.55	0.14	<0.005	<0.005	0.025

Table 2. Submerged-arc-welding consumables

Weld	Wire (AWS)	Flux (Basicity Index)	Principal Alloy
PF1	Oerlikon SD3 - 1 Ni (ENi1)	Oerlikon OP121TT (3.0)	1% Ni
PF2	ESAB Autorod 12.34 (EA2)	ESAB OK10.62 (3.4)	0.4% Mo
PF3	Oerlikon SD3 - 1 NiMo (EF3)	Oerlikon OP121TT (3.0)	1% Ni - 0.4 Mo

Table 3. Submerged-arc-welding parameters

Pass #	Current (Amps)	Wire Feed Speed (mm/s)	Voltage (Volts)	Travel Speed (mm/s)	Electrical Stick-out (mm)
Side 1					
1	510	16.9	34	10.2	32
2	560	19.0	34	9.3	32
3-6	560	19.0	34	8.5	32
Side 2					
7-8	560	19.0	34	8.5	32
9-10	560	19.0	34	10.2	32

Table 4. Tensile properties of quenched and tempered base and weld metals

Material	Yield Strength (MPa)	Ultimate Strength (MPa)	Elongation %	Reduction in Area %
A633 Gr E	757	839	23	56
PF1	615	688	25	70
PF2	763	836	20	62
PF3	798	889	20	58

Table 5. Weld metal microhardness

Weld #	As-Welded	Quenched and Tempered
PF1	198 194 201 200 (198)	225 215 211 220 (217)
PF2	218 237 228 216 (224)	277 263 261 (265)
PF3	226 226 207 229 (222)	261 248 270 259 (260)

( ) average - DPH reading using 500g load

Table 6. Chemical composition of weld metals

Weld #	Element, wt. %													
	C	Mn	Si	S	P	Al	Sn	Ni	Cr	Mo	Cu	V	Nb	C. E.
PF1	0.12	1.35	0.249	0.008	0.019	0.015	0.010	1.12	0.062	0.04	0.23	0.026	0.017	0.43
PF2	0.13	1.42	0.319	0.007	0.017	0.015	0.010	0.088	0.051	0.34	0.23	0.035	0.018	0.46
PF3	0.13	1.39	0.286	0.007	0.016	0.020	0.010	0.610	0.052	0.37	0.16	0.035	0.019	0.49

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

Table 7. Proposed optimum weld metal composition

C	Mn	Ni	Mo	V + Nb
<0.10	≤1.50	≤0.50	≤0.25	≤0.020

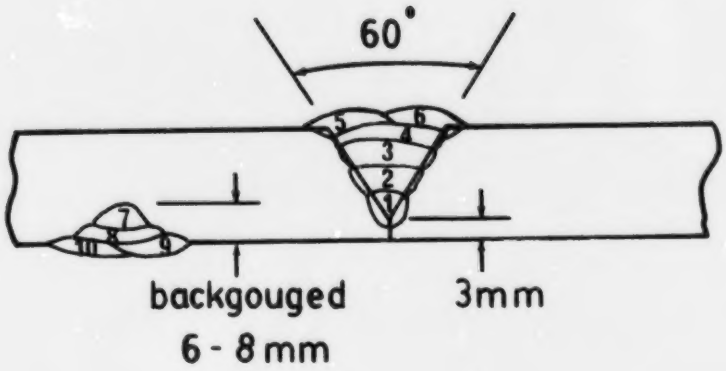


Fig. 1. (a) Welding joint design and bead sequence showing backgouging procedure. (neg 13523)

Fig. 1. (b) Typical marco section of experimental welds (Mag 2X). (neg 13604)

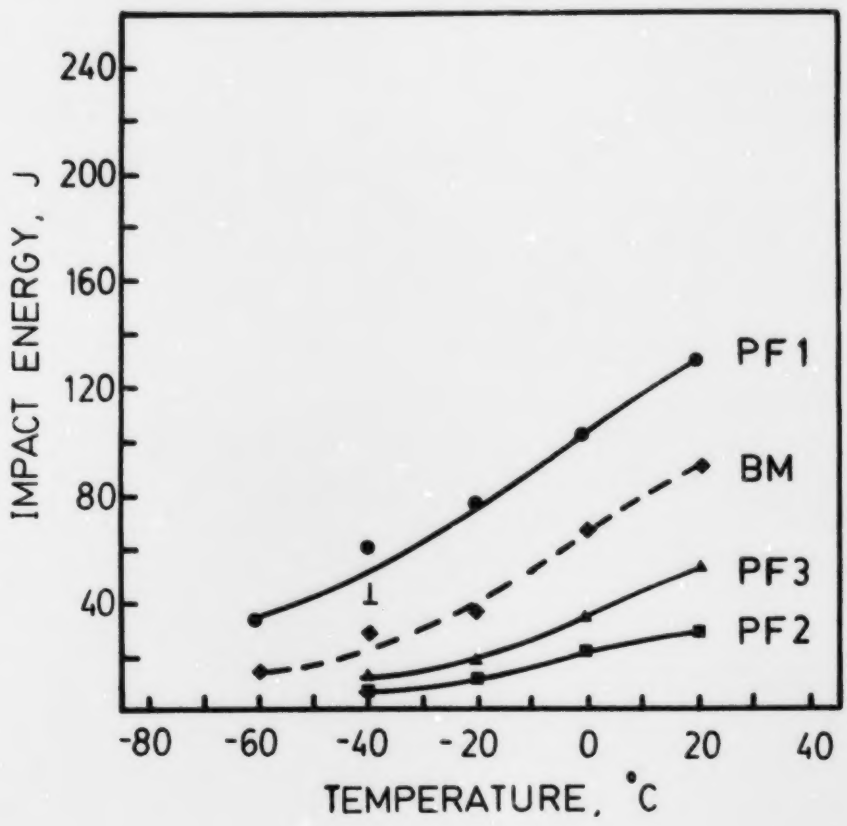
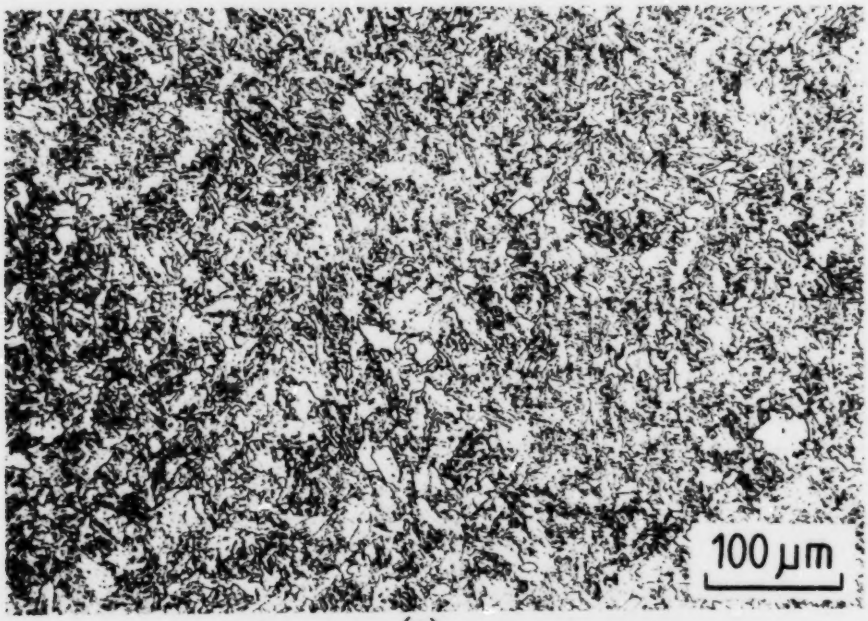
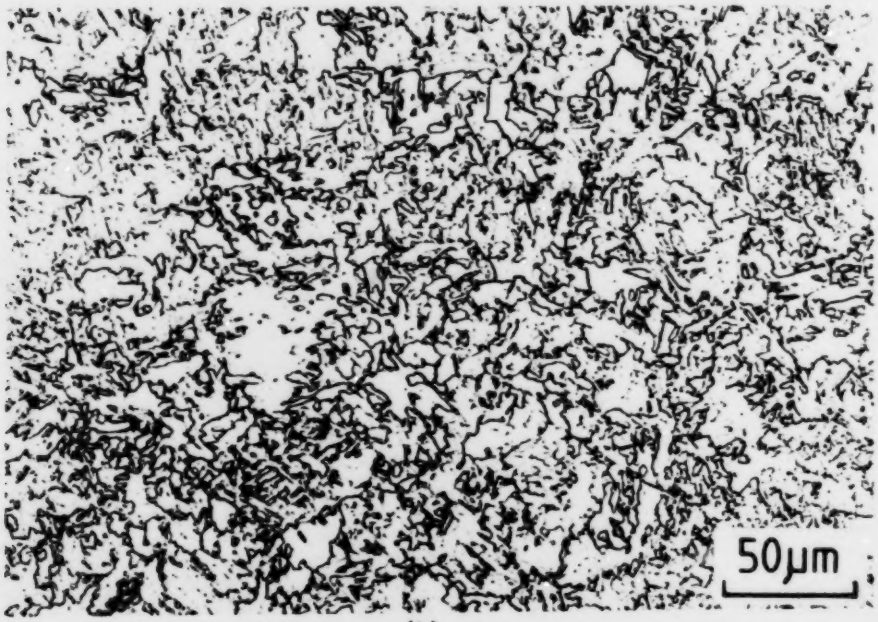


Fig. 2. Charpy transition curves of base and weld metals after quench and temper P.W.H.T. (neg 13522)



(a)



(b)

Fig. 3. Weld metal microstructure of weld PF1 after quench and tempering (2% nital). (neg 13605, 13606)

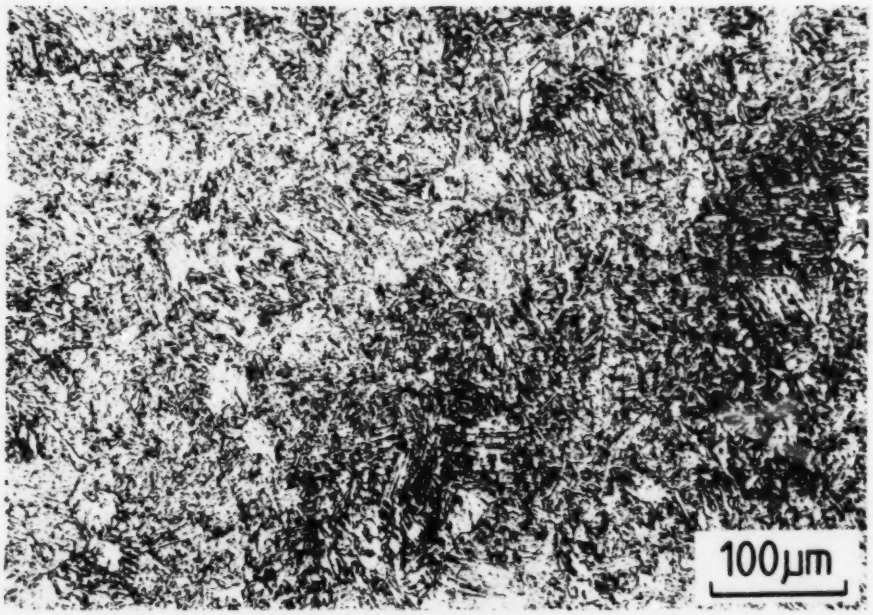


Fig. 4. Weld metal microstructure of weld PF2 after quench and tempering (2% nital). (neg 13607)

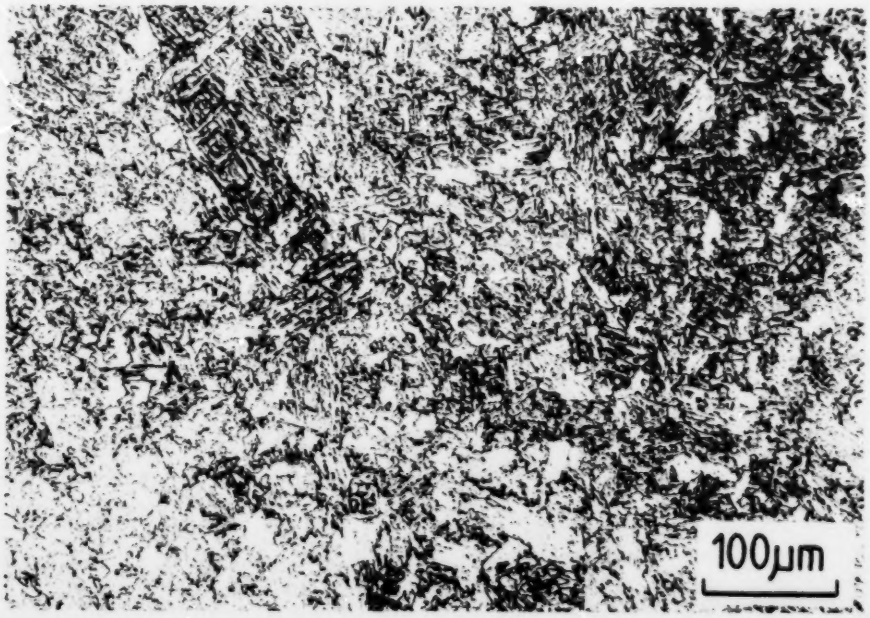


Fig. 5. Weld metal microstructure of weld PF3 after quench and tempering (2% nital). (neg 13608)

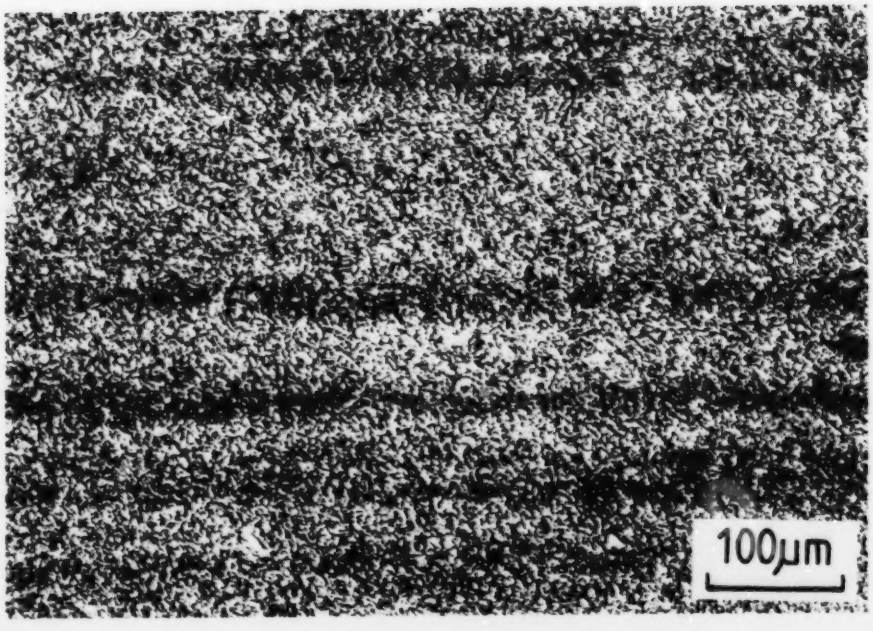


Fig. 6. Base metal microstructure after quench and tempering (2% nital). (neg 13609)